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2019-10

Morone , P & D'amato , D 2019 , ' The role of sustainability standards in the uptake of bio-based chemicals ' , Current opinion in green and sustainable chemistry , vol. 19 , pp. 45-49 . https://doi.org/10.1016/j.cogsc.2019.05.003

http://hdl.handle.net/10138/304566
https://doi.org/10.1016/j.cogsc.2019.05.003

Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in
Green and Sustainable Chemistry

Review article

The role of sustainability standards in the uptake of bio-based chemicals

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As bio-based chemicals become more technically and financially competitive, spurring the further development of the chemical industry, they are also presented as more sustainable alternatives to petrol-based chemicals. We argue that an *ad hoc* and coordinated regulatory and standards framework channeling sustainability efforts would legitimize sustainability claims for bio-based products.

Keywords
Bioeconomy, Bio-based chemicals, Standards, Policy, Sustainability.

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Current Opinion in Green and Sustainable Chemistry 2019, **19**:45–49

This review comes from a themed issue on **New Business models, ethics, legislation and economics**

Edited by **Michael Hiete** and **Pasquale M. Falcone**

https://doi.org/10.1016/j.cogsc.2019.05.003

Background and rationale

In the past, high value-added bio-based chemical products were rarely able to compete with traditional chemical processes and products. However, as technology and chemical methods have improved, the bio-based chemical industry has become more viable and is now poised to take over a larger share of the market. Estimates of the global renewable chemicals market foresee for 2020 an increase up to $85.6 billion ($51.7 billion in 2015) [1]. In addition to renewing and further developing the chemical industry, bio-based chemicals are, at least in theory, deemed to be more sustainable alternatives to petrol-based.[1]

On these premises, a transition to a bioeconomy is supported at the political level almost worldwide [2], and it is slowly being received at company level [3]. A sustainable bioeconomy should address the circularity of production systems, as well as ecological and social sustainability [e.g. Ref. [4]]. This is supposed, at least in theory, to entail the sustainable sourcing and efficient (re)use of living biomass to substitute for fossil resources; the cascading use of biomass to prioritize the creation of high-value products (e.g. bio-chemicals vs bio-fuels); and the design, reuse, and disposal of sustainable products and services [5]. However, "the rapid development of this innovative industry has outpaced policy development in several aspects that have societal concerns" [[6], p. 221].

Given the contemporaneity and relevance of the phenomenon, there is an urgent need to formulate guidelines for a common framework promoting the development of sustainability standards, which should take a value-chain perspective (from feedstocks provision to end-user consumption) and follow a cradle-to-cradle approach (including cascading effects and end-of-life options). Such standards would have a dual function: on the one hand, they would support the business models promoting economic viability, environmental protection, and social responsibility and on the other hand, they would prompt the uptake of bio-based chemicals, boosting their market penetration by stimulating green purchasing behaviors among consumers and/or by legitimizing policymakers who support more sustainable products. However, sustainability standards also bear some potential shortcomings, such as the creation of entry barriers, the imposition of a steep learning curve of adaptation, and the imposition of costly and lengthy assessment exercises [7].

Against this background, the aim of this article is to highlight the potential role of sustainability standards in the development of the bio-based chemical industry (with the exception of biofuels, which would deserve an article on their own) and thus setting guidance for policy actions. In section 2, we briefly articulate the role of standards in stimulating the uptake of emerging innovation niches; in section 3, we provide an overview of existing standards which apply to bio-based products; and in section 4, we discuss implications for the

[1] Note that several scholars have criticized the dogmatic assumption of the bioeconomy's self-evident sustainability [30,31].

development of an overarching policy framework in the bioeconomy.

Standards and their role in the uptake of innovation niches

Governance processes in a globalized world have shifted in the past five decades from solely command and control instruments to policy mixes including economic and diffuse instruments [8,9]. A multifaceted approach to governance is deemed necessary to tackle sustainability challenges characterized by complex, interlinked, transnational, and transgenerational dynamics [10]. This process has gone hand in hand with the growth of the role played by various societal actors (NGOs, grassroots movements, industry associations, etc.), which shape policy interventions either through advocacy or, more directly, public–private partnerships[2] [7].

In this context, standard setting processes have emerged as important tools for steering the trajectory of change [11,12], which typically emerges through a participatory approach involving a plethora of actors. In this regard, the distinction between mandatory and voluntary standards is significant.[3]

Mandatory standards are established by national or supranational governments or organizations, with compliance enforced through liability penalties. In the context of chemical industries, the Registration, Evaluation, Authorization and Restriction of Chemicals directive [13] is a regulation regarding all chemicals and applying to companies producing in or shipping into the European Union and its member countries. Voluntary standards, certification, and label schemes are developed with various degrees of societal engagement, normally orchestrated by supranational or international organizations, industry associations, or NGOs [14]. For instance, ISO standards are developed through consultation with experts and regulatory authorities. The Responsible Care initiative, developed by chemical industry associations, represents a sector-specific standard. Multiple voluntary standards are not mutually exclusive or competitive [14]. Furthermore, voluntary standards may contribute to support parts of regulative systems, as the borders between mandatory and voluntary reporting/standards becomes increasingly blurred [15].

Standardization processes have an important role in fostering innovation [16], which has already been observed in the literature for the transition to other emerging technologies [17]. From a system perspective, standards work to reach "compatibility between jurisdictions, a pivotal point underpinning international trade" [17, p. 3798]. While they impose additional costs in terms of expertise and assessments on firms, they also foster the advancement and sharing of best practices and capacities.

At company level, mandatory standards regulate access to markets, while voluntary standards further contribute to structuring, harmonizing, and legitimizing companies' efforts at sustainability [16]. Companies adhering to voluntary standards or guidelines also set the pace for others operating in the same context or along their supply-chain. Sustainability-oriented activities can have strategic benefits for companies in terms of cost and risk reduction, gaining competitive advantage, value creation in synergy with stakeholders, and ultimately developing legitimacy [18,19].[4]

The market drive for standards and certification depends on the product and is overall still limited. However, standard also legitimize the adoption of policy incentives to more socially and environmentally desirable products or services [15]. For instance, public procurement is a possible avenue to support emerging innovation niches in developing competitiveness on economic and social performance [6,10,20].

Standards in the context of bio-based products

There are several national and international mandatory and voluntary standards and certification schemes that apply specifically to bio-based products. Most of them address bioenergy and biomaterials or food and feed [21,22]. The International Sustainability & Carbon Certification is a global-level certification system covering the entire supply chain and multiple bio-based feedstocks. The International Sustainability & Carbon Certification is relevant for liquid biofuels as well as chemicals and plastics [21].

An important process at European level is the development of standards by the European Committee for Standardization [23], in regard to fully bio-based products (excluding food, feed and energy) or to the bio-based parts of product on horizontal sustainability aspects (economic, environmental, and social). The technical committee (TC 411) works on standards for

[2] A case in point is the successful experience of the Bio-based Industries Joint Undertaking (BBI JU), a public–private partnership between the European Commission and the Bio-based Industries Consortium (a private not-for-profit organization representing large and small industries operating in the bio-based sector). BBI JU acts as a clearing house to establish a critical mass around the bioeconomy, fostering radical innovation through the promotion of industry–academic joint research projects and, ultimately, promoting the market uptake of bio-based products [32].

[3] Standards are most often intended to be voluntary, but because they influence and at times support the mandatory frameworks, in the context of this article, we shall refer to both mandatory and voluntary processes.

[4] In spite these positive aspects, it should be noted that various authors maintain that voluntary standards might show some limitations at addressing environmental problems. For instance, in the presence of voluntary standards proliferation, standards legitimacy might become an issue both on the consumption side (in association with a phenomenon such as the "label fatigue", which may lead consumers to indiscriminately purchase products "greenwashed" with non-credible labels) and on the production side (where producing firms may be attracted to participate in loosely regulated standards, which may encourage greenwashing practices) [26].

terminology, biosolvents (performance, toxicity, ecotoxicity, biodegradability, safety, and sustainability), bio-based carbon content, sustainability, and lifecycle assessment, certification, and declaration tools (characteristics to assess and report).

A thorny issue concerns the bio-based content required in a product for it to be determined as bio-based. Existing certification refers to bio-based carbon content and is based on the European standard EN 16785-1.[5] This standard is relevant to determine the bio-based content using the radiocarbon analysis and elemental analysis. However, it does not provide any guidance on discriminating among what could be referred to as a bio-based product and what could be not. In this regard, doubts remain on applying sustainability standards for bio-based products which, in fact, are mostly petroleum derived.[6]

Criticism to standard terminology (EN 16751:2016) has been pointed out, such as that because threshold values (i.e. quantifiable criteria) are not provided, the standard is limited to communication purposes or for supporting the development of specific standards and certification schemes [21]. Additional concerns regard the sustainability assessments of bio-based products (EN 16760:2015). As stated by Ladu and Blind [24] "Existing standards are limited to cradle-to-gate and do not yet recognize the advantages of bio-based products at the end of the value chain and end-of-life". In light of the existing and emerging standards and certification schemes, needs of standardization within the context of emerging products in the bioeconomy remain a high priority, despite the efforts of national, regional, and international committees [21,25].

Policy implications

According to a recent analysis of policy documents [26], several countries rely heavily on voluntary standards and certifications to manage bioeconomy-related risks. However, the landscape of existing standards applicable to bioeconomy products is fragmented. There is currently little scientific understanding of how traditional standards setting organizations (e.g. ISO) are able to address new bioeconomy products and sectors and of how emerging standards, such as the ones developed by European committee for standardization (CEN), are able to convey information about sustainability performance, while targeting a wide range of bio-based products (especially high value-added products).

From the perspective of multiactor governance, standards play a delicate role in the transition to bio-based chemicals: on one hand, they impose additional cost and capacity burdens on companies, but on the other hand, they can support the marketization and improvement of products or services. In particular, to stimulate the transition toward bio-based chemicals sector, emerging innovation niches should be protected in the early phases of development as long as necessary to destabilize and "unlock" the dominant system and overcome resistance from incumbent actors [27]. This is of utmost importance when considering the pressure often faced by new technologies and innovative products competing with well-established incumbent technologies/products.

Sustainability standards, associated with policy actions aimed at supporting the emerging niche, can be a fundamental leverage point for spurring the desired transition in the bioeconomy [26]. A case in point is represented by public procurement. For instance, public procurement represents 14% of gross domestic product (GDP) in the European Union and in association with compliance with sustainability standards (e.g. through green public procurement) could be an important avenue for the uptake of bioeconomy products and services [28]. In the United States, the BioPreferred program assists the market expansion of bio-based products through a combination of voluntary certification and public procurement where bio-based products are preferred to fossil-based ones [29].

The development of overarching policy frameworks for bio-based chemicals, although desirable, is however challenging because of lack of coordination of existing standardization systems [25]. Additional challenges arise from the diversity of bio-based chemicals and related production volumes, as well as the diversion of policy support to other uses of biomass (e.g. bioenergy) [6,24]. In light of these considerations, three main issues deserve further research and policy attention in the context of standards development for bio-based chemicals.

First, the effectiveness and efficiency of standards in addressing and verifying sustainability issues. The identification of appropriate sustainability indicators is especially crucial in the context of an emerging phenomenon such as the bioeconomy, which is largely proposed by interested parties as a paradigm shift toward a more sustainable production—consumption system, but it is also criticized by scholars and practitioners for its conceptual and technical limitations in doing so [30,31].

Second, as governance processes become more inclusive and pluralistic, new issues emerge with regard to the legitimacy of non-governmental actors bringing their views and agendas to the table. Third, the additional costs of the standardization of bio-based chemicals

[5] See also the American standard ASTM 6866 "Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis" [33], and also the standards by the CEN TS 16137 "Plastics—Determination of bio-based carbon content".

[6] Note, that product-specific (vertical) standards for lubricants, solvents, plastics, and surfactants independently require bio-based carbon to be at least 25%.

should not increase its competitive disadvantage compared with well-established incumbent technologies/products.

The first and second of these three issues entail a more bottom-up approach, involving a plurality of actors both in the definition and legitimation process of appropriate principles, criteria and indicators for the sustainability assessment (including researchers, NGOs, industries, and practitioners). The third issue would, in its turn, involve a top-down approach requiring direct intervention from policymakers to compensate for the cost of the sustainability assessment through policies that support the creation of a level playing field. This top-down intervention does not correspond to *ad hoc* policies for bio-based products, rather it implies a way of internalizing external costs, setting a premium for sustainability.

Acknowledgements

This article was developed in the context of the projects STAR-ProBio (Sustainability Transition Assessment and Research of Bio-based Products) and OPES (OPerationalizing Ecosystem services in business Sustainability: drawing from green and circular-bioeconomy). STAR-ProBio project is funded by the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement No. 727740, Work Program BB-01-2016: Sustainability schemes for the bio-based economy. OPES project is funded by Academy of Finland (Grant 315912).

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